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SUBSTITUTE SPECIFICATION

STALL DETECTION CIRCUIT AND METHOD

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention is directed to the monitoring of motor operation and, more particularly, to a stall detection circuit for two-phase, four-coil stepper motors operating in two-phase-on mode.

Description of the Related Art

[0002] Two-phase, four-coil stepper motors include a permanent magnet rotor 10 with multiple pole pairs, namely having two stator phases made up of two coils connected in series in each phase, as shown in Figure 1.

[0003] Under typical operation, one H-bridge driver powers each phase. As shown in Figures 2A-2C, the standard H-bridge circuit includes a first path having a first switch S1 connected in series with a second switch S2 and, in parallel therewith, a second path having a third switch S3 in connected in series with a fourth switch S4. A pair of coils, coil 1 and coil 2, are connected in series on a branch between a node on the first path between the first and second switches, and a node on the second path between the third and fourth switches. A respective diode D may be connected to nodes on either side of each switch. While the first and second switches are connected in series, in operation of the

circuit, the first and fourth switches act in series, and the second and third switches act in series, as explained herein.

[0004] Particularly, the standard H-bridge step sequences for forward, reverse and braking modes are depicted in Figures 2A-2C, respectively. The circuitry with the third and fourth coils of the second phase is arranged in the same way as that shown for coil 1 and coil 2, only 180 electrical degrees out of phase.

[0005] In the forward sequence shown in Figure 2A, for example, current alternatingly flows through the first switch S1, coil 1 and coil 2, and the fourth switch S4, and then through the third switch S3, coil 2 and coil 1, and the second switch S2. In this configuration, back electromotive force (EMF) generated by the motor is masked by the supply voltage. Transient voltage across the switching coil shows little or no change, regardless of the rotor movement. It is therefore difficult to discern if the rotor has been blocked or rotated in the wrong direction.

[0006] Therefore, a need exists for a stall detection circuit providing a method for substantively differentiating normal running mode from a stall condition.

SUMMARY OF THE INVENTION

[0007] In view of the foregoing, one object of the present invention is to avoid the difficulties associated with the failure to recognize a motor stall condition.

[0008] Another object of the present invention is to provide a circuit that is able to detect changes in back EMF as generated by different rotor conditions to determine if the rotor is in normal running mode or has been blocked or rotated incorrectly.

[0009] A further object of the present invention is to provide an improved H-bridge circuit construction that includes an additional current flow path to clarify back EMF detection.

[00010] It is yet another object of the present invention to provide a circuit that is not complex in structure and may be implemented within existing circuits at low cost but yet used to efficiently monitor rotor conditions.

[00011] In accordance with this and other objects, the present invention is directed to a stall detection circuit having an H-bridge configuration with first and second windings, in which an additional circuit pathway is provided at a point between the two windings and extending to ground. During the transition between step sequences, the circuit employs a monitoring phase in which the low side driver is turned off such that current passes through only the first winding and then is diverted to ground via the additional pathway. The second coil is then used to monitor the motor's back EMF which, in turn, indicates whether the rotor is in normal running mode, stall or reverse condition.

[00012] These together with other objects and advantages which will become subsequently apparent reside in the details of

construction and operation as more fully hereinafter described and claimed, reference being had to the accompanying drawings forming a part hereof, wherein like numerals refer to like parts throughout.

BRIEF DESCRIPTION OF THE DRAWINGS

[00013] Figure 1 shows a conventional motor with two stator phases made up of two coils connected in series in each phase;

[00014] Figure 2A is a circuit diagram of a conventional H-bridge step sequence for a stepper motor in the forward direction;

[00015] Figure 2B is a circuit diagram of a conventional H-bridge step sequence for a stepper motor in the reverse direction;

[00016] Figure 2C is a circuit diagram of conventional H-bridge step sequences for a stepper motor under braking conditions;

[00017] Figure 3 illustrates a stall detection circuit for a stepper motor in accordance with the present invention;

[00018] Figure 4 graphically depicts the behavior of the motor's back EMF under normal running, stall and reverse conditions;

[00019] Figure 5A illustrates a variation of the stall detection circuit for a stepper motor in accordance with the present invention; and

[00020] Figure 5B illustrates a further variation of the stall detection circuit for a stepper motor in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[00021] In describing a preferred embodiment of the invention illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, the invention is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose.

[00022] The present invention is directed to a stall detection circuit such as that shown representatively in Figure 3. As with the conventional circuit shown in Figures 2A-2C, one H-bridge driver powers each of the two steps of the four-coil stepper motor operating in two-phase-on mode. During a first step, switches S1 and S4 are closed, and during a second step, switches S3 and S2 are closed. The sequence of the steps changes according to whether the motor is in forward or reverse operating condition, as shown in Figures 2A and 2B, respectively.

[00023] According to the present invention, the stall detection circuit includes an additional fifth switch S5, which may be embodied as a transistor, connected at a branch node between coil 1 and coil 2 and ground, as shown in Figure 3. A resistor R is also provided between the switch S5 and the node between the windings.

[00024] In order to monitor the back EMF during the transition between steps, the fifth switch S5 is turned on or closed at the end of each step sequence and, a few microseconds thereafter, the low-side driver S4 is turned off or opened. When switch S1 and switch S5 are on and the low-side driver S4 is off, current flows through the fifth switch S5 to ground and the sense voltage across switch S4 is used to monitor the back EMF. Of course, the circuit may be constructed with any one of the four coils acting as the back EMF monitoring coil.

[00025] A significant increase in transient current level during this monitoring phase is prevented by matching the resistance value of R to the resistance of the monitoring coil, coil 2. In this way, the dramatic drop in current to coil 2 that would otherwise result upon the closing of the fifth switch S5 and the opening of the fourth switch S4 is avoided through the mediating action of the series resistance R.

[00026] During the monitoring period between the step sequences, as is depicted in Figure 3, upon the opening of the fourth switch S4, residual current at coil 2 flows through the diode D1 until such current is extinguished. Thereafter, the back EMF produced by the motor generates the current flow indicated by the dotted line 12 from which the sense voltage is detected.

[00027] As illustrated in Figure 4, the behavior of the motor's back EMF is distinctly different during normal running mode as

compared with a stall condition. Therefore, by monitoring the differences in the sense voltage, V_{sense}, coming off of coil 2, it is possible to determine from the back EMF, which is now free of any masking by the supply voltage, whether the motor is operating normally or if, instead, the rotor has been blocked or rotated incorrectly.

[00028] More particularly, Figure 4 depicts the voltage yield at the V_{sense} pin from the three conditions of normal, stall and reverse. As used in Figure 4, "normal" refers to the direction in which the rotor is moving when engaged in the intended step sequence. The intended step sequence may be forward mode or reverse mode. To illustrate, for the sake of simplicity each of Figures 3, 5A and 5B depict only one of the switching conditions of Figure 2, namely the forward condition. Therefore, when in the forward condition, "normal" indicates that the rotor is moving in the forward mode as shown in Figure 2A while "reverse" then indicates that the rotor has been stalled and is now moving in the direction opposite that which is intended. Were the intended condition to be the reverse mode, then "normal" would correspond with Figure 2B, while reverse would occur when the rotor, having stalled, begins moving "forward".

[00029] Accordingly, the voltage level output in the stall condition is indicated by VDD/2 and the voltage level in the reverse condition, i.e., the direction opposite the intended step

sequence, is indicated by VDD. Thus, the two voltage levels effectively differentiate reverse and stall conditions from the normal direction of rotor movement, with the greatest back EMF being generated in the "reverse" condition.

[00030] Further embodiments of the stall detection circuit according to the present invention are shown in Figures 5A and 5B. In Figure 5A, the fifth switch S5 and resistor R are replaced with a resistor R1. The resistance value of R1 is preferably a few orders of magnitude larger than the resistance value of coil 2. In an HVAC system with approximately 100 Ohms winding resistance, for example, the resistor R1 would be sized at a few kOhms, preferably 3.3-5 kOhms. This ensures that steady state current diverting to the added resistor R1 when S4 is closed remains low, so that most of the power is delivered to both of the windings, thereby maximizing motor efficiency.

[00031] As shown in Figure 5B, a diode D2 can be placed in parallel with the resistor R1. ~~Upon initiation of the monitoring phase with the opening of S4, the diode D2 quickly removes residual current from the sense coil 2, which may produce a more pronounced change in coil voltage and thereby improve detection.~~

[00032] According to a method of the present invention, the stall detection circuit having the additional current pathway in an H-bridge configuration is operated in a sequence of steps as follows. During a first step, current is driven from the first switch to the

fourth switch through the first and second coils. Preparatory to the second step, the fourth switch is opened while the first switch remains closed so as to divert the current to the additional current pathway extending from between the two coils to ground. After residual current in the second coil is extinguished, back EMF generated by the motor is detected through the second coil as a sense voltage, from which the motor operating condition may be determined.

[00033] When the additional circuit pathway includes a fifth switch, as shown in Figure 3, the method further includes the step of closing the fifth switch a few microseconds before the fourth switch is opened, as depicted in Figure 4.

[00034] In summary, due to the distinctive differences in the motor back EMF profile generated by normal motor operation versus that produced in a stall or reverse condition, if the stepping sequence is modified such that a monitoring phase, in which the phase voltage is momentarily extinguished, is executed for a short time prior to stepping to the next sequence, a stall condition can be easily detected from the back EMF generated by the motor. For HVAC actuators, only a few milliseconds of sense time are typically needed. The overall output torque of the motor is therefore not compromised.

[00035] Upon detection of a stall condition, the driver (not shown) or other control unit used in connection with an H-bridge

configuration, as would be known by persons of ordinary skill in the art, can generate a warning signal and then, depending upon the particular system specification, either remove power from the motor or remain in the last sequence shown in Figure 2C to brake the motor.

[00036] The foregoing descriptions and drawings should be considered as illustrative only of the principles of the invention. The invention may be configured with different combinations of electrical components and is not limited by the dimensions of the preferred embodiment. Numerous applications of the present invention will readily occur to those skilled in the art. Therefore, it is not desired to limit the invention to the specific examples disclosed or the exact construction and operation shown and described. Rather, all suitable modifications and equivalents may be resorted to, falling within the scope of the invention.